DISTRIBUTION OF GRAIN FUMIGANTS IN SILO-TYPE ELEVATOR TANKS BY AERATION SYSTEMS

Marketing Research Report No. 915

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE

USE PESTICIDES SAFELY

If you use pesticides, apply them only when needed and handle them with care. If pesticides are handled or applied improperly, or if unused portions are disposed of improperly, they may be injurious to humans, domestic animals, desirable plants, honey bees, and other pollinating insects, fish, and wildlife, and may contaminate water supplies.

To protect the ultimate consumer of food crops and animal products, the use of insecticides is regulated under the Federal Insecticides, Fungicides, and Rodenticides Act and the Federal Food, Drug, and Cosmetic Act. The rate and method of application and any resulting residues must comply with the requirements of these two acts. Products in violation of these acts are subject to Federal action.

For experimental purposes, dosage rates of methyl bromide that were used in the study exceeded those officially recommended for insect control. Some residues, consequently, were greater than the tolerances established. The established tolerances for grains, in parts per million, of inorganic bromides from all sources are:

Grain	*Tolerances* (p.p.m.)
Barley	50
Corn	50
Oats	50
Popcorn	240
Rice	50
Rye	50
Sorghum	50
Wheat	50

Carbon disulfide and carbon tetrachloride are exempt from the requirement of a tolerance.

Fumigants should be used and handled with extreme care. The directions and precautions on the label should be followed carefully. The correct gas mask and canister should always be worn for the fumigant being used.

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ACKNOWLEDGMENTS

One series of tests was conducted in cooperation with the Michigan Chemical Corporation, Saint Louis, Mich., that supplied the methyl bromide. Elevator tanks filled with sorghum, located at Placedo, Tex., were provided by the Vic-Cal Grain Company. ARS personnel assisting in this study were Reed Hutchison, who determined airflow data, and John Schesser, who carried out some of the entomological phases.

A second series of tests was conducted in an elevator tank filled with wheat, provided by the Abilene Flour Mills, Abilene, Kans. The methyl bromide was supplied by the Dow Chemical Company, Midland, Mich. ARS personnel assisting were G. L. Kline and H. H. Converse who determined airflow data.

A single test was conducted in two elevator tanks filled with wheat provided by the Topeka Mill and Elevator Company, Topeka, Kans. The Dow Chemical Company supplied the liquid fumigant and conducted the mass spectrometry analyses of the fumigant samples. H. H. Converse of Agricultural Research Service, determined the airflow data.

R. L. Ernst of Agricultural Research Service assisted in the entomological phases of all of the tests.

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DISTRIBUTION OF GRAIN FUMIGANTS IN SILO-TYPE ELEVATOR TANKS BY AERATION SYSTEMS

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SUMMARY

All the fumigation tests presented in this report were conducted in silo-type concrete elevator tanks. The fumigants were distributed throughout the tanks by mechanical aeration systems operated at airflow rates used in cooling grain.

In the three tests conducted at Placedo, Tex., grain sorghum was fumigated with methyl bromide released into the overhead space and pulled down through the grain. The fan was stopped when the gas reached the bottom of the tank. No return duct was used. Distribution of the gas in the first test at 3½ pounds per 1,000 cubic feet indicated the need for an increase in both the dosage applied to the sorghum and the fan running time required to obtain distribution to the bottom of the tank. The application of 5 pounds per 1,000 cubic feet in the second test provided substantial concentrations of gas, but distribution within the tank indicated a marked channeling of the fumigant as it was drawn downward through the grain mass. Channeling was effectively reduced in the third test at 4 pounds per 1,000 cubic feet by pulling air through the grain in three other tanks in addition to the one being fumigated. This reduced the airflow, and the fumigant was distributed more uniformly.

High mortality of the adult test insects (rice weevils) was obtained in each test; however, effective control of the immature rice weevils was limited to the third test in which the reduced airflow was used. The viability of the sorghum was low before fumigation, but each of the methyl bromide dosages tested reduced the viability significantly. There was a general increase in the bromide residue in samples taken after fumigation. Inorganic bromide residues exceeded the established tolerance of 50 parts per million (p.p.m.) in one-third of the samples analyzed. No correlation was evident, however, between the amount of methyl bromide applied and the resulting bromide residues.

In the tests conducted at Abilene, Kans., two single-pass fumigations were conducted in a wheat-filled silo-type elevator tank to determine the effect of an experimental vertical aeration duct on air movement and fumigant distribution. In the first test, the methyl bromide was released into the overhead space and pulled down through the wheat. In the second test, the methyl bromide was released in the vertical duct and pushed up through the wheat. No return duct was used in either of the two fumigations.

Static pressure readings taken before each test indicated that a fairly uniform flow of air through the wheat mass was produced by air movements in either direction. However, a comparison of the gas distribution patterns during the two fumigations revealed that operation of the fan on positive pressure (pushing air upward through the wheat) produced a slight channeling of the fumigant up the side of the tank opposite the vertical duct and around the highest peak in the wheat pile.

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In a single test, conducted at Topeka, Kans., two adjacent silo-type elevator tanks filled with wheat were connected at the top and bottom with flexible hose and fumigated simultaneously with a liquid fumigant composed of carbon tetrachloride, 82.5 percent by weight; carbon disulfide, 16.5 percent by weight; and inert ingredients, 1 percent by weight. A fan unit placed between the bottom connections recirculated the fumigant within the two tanks.

Concentration data revealed that no significant separation of the fumigant components resulted from the recirculation of the liquid fumigant through nearly 280 feet of wheat.

Test insects in small screen cages were taped to the sampling lines at 20-foot intervals. Mortality of the test insects was high in each tank.

TESTS AT PLACEDO, TEX.

Fumigation tests were conducted in sorghum-filled, silo-type concrete elevator tanks located at Placedo, Tex., to obtain data for developing application techniques and establishing dosage requirements for the fumigation of sorghum with methyl bromide.

Procedure

Three tanks of an elevator were fumigated with methyl bromide by use of the single-pass method of fumigation at dosages of 3½, 5, and 4 pounds per 1,000 cubic feet. The tanks were 115 feet high, with an inside diameter of 18 feet. Each tank contained approximately 25,000 bushels of sorghum. The moisture content of the sorghum ranged from 12 to 14 percent and the grain temperatures from 90° to 105° F.

The elevator was equipped with two fans, one located on each side at the midpoint in the basement. The intake of each fan was attached to a single duct running the entire length of the elevator. The octagonal duct system in each tank was connected to the single duct through gates opposite each tank (fig. 1). This aeration system was installed in the elevator so that the operator could aerate as many as four tanks at the same time with each fan. Each fan was approximately 5 feet in diameter and had a 50-horsepower (hp.) motor.

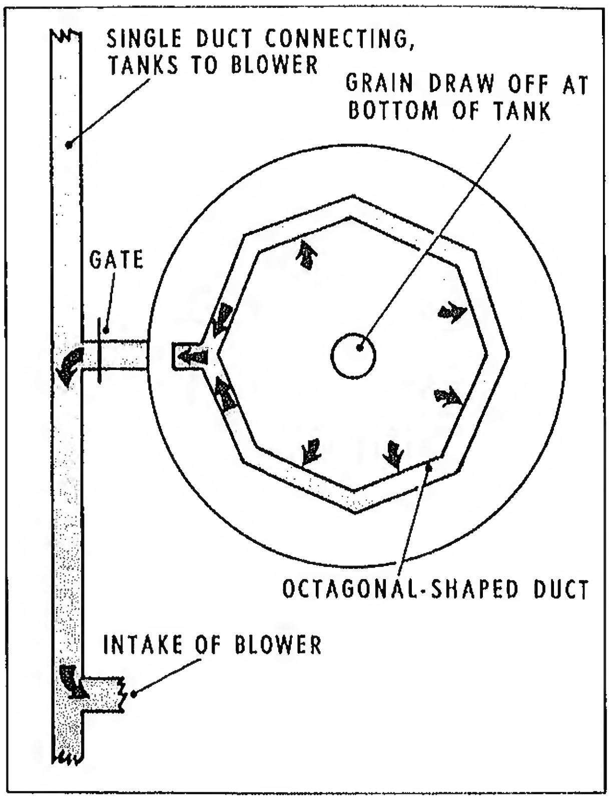

FIGURE 1.—Top view of the duct system.

The use of the recirculation method of fumigant distribution was not practical with this aeration system. Numerous leaks around the gates, even when they were closed, resulted in more air being returned by way of a return duct attached to the outside of the elevator than was drawn from the bottom of a single tank. Adaptation of the forced distribution method in this elevator was, therefore, limited to single-pass applications.

Three cables of No. 6 wire were suspended in each tank and securely fastened at both top and bottom. One cable was placed near the north wall of the tank, a second near the south wall, and a third in the center. The gas sampling lines were taped to the cables at selected levels (fig. 2).

As the tanks were filled with sorghum, small cloth bags containing adult and immature rice

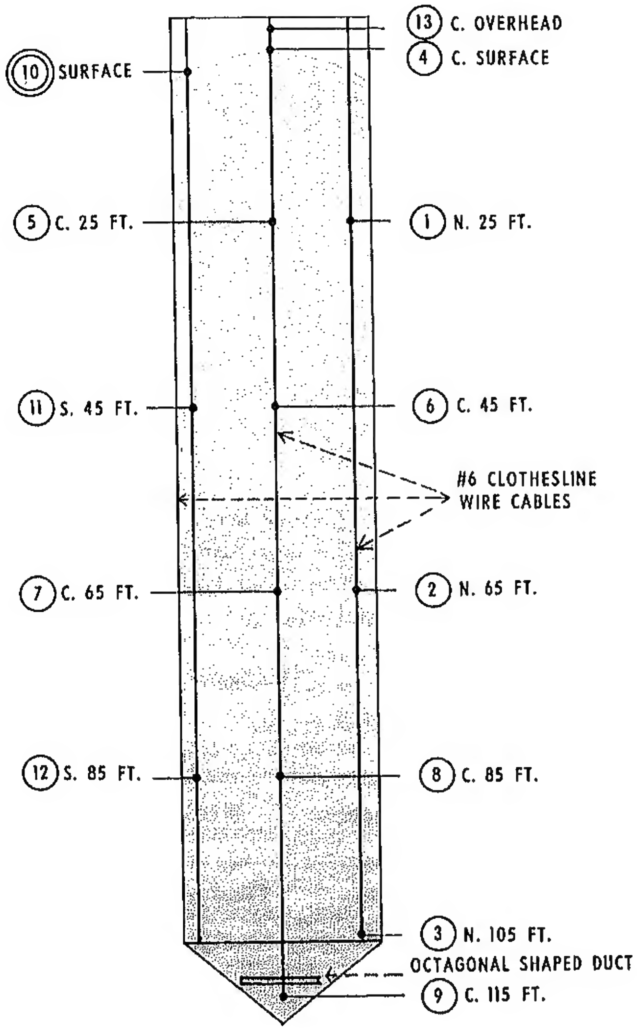

FIGURE 2.—Location of the aeration duct and the gas sampling points throughout the column of grain.

weevils enclosed in screen cages were placed as closely as possible to the gas sampling points. The tanks were filled at the rate of 10 feet per hour. Samples of sorghum for bromide residue and germination tests were taken from the conveyor belts at 2-hour intervals or at every 20-foot level. After the 24-hour fumigation period, similar samples were taken as the tank was being emptied. These methods for placing insects and obtaining grain samples for residue and germination studies were repeated in each of the three tests.

The methyl bromide was introduced into the overhead space through a copper tube suspended above the grain surface. The rate of application of the methyl bromide was determined by weighing the gas cylinder on a scale during application of the gas. Gas samples were taken at 13 points (fig. 2) at 30 minutes, and 2, 4, 8, and 24 hours after the gas was applied. Additional analyses were made during evacuation of the methyl bromide at the end of the 24-hour fumigation period.

For the first test a dosage of 3½ pounds of methyl bromide per 1,000 cubic feet was applied to one of the tanks. The methyl bromide was released into the overhead space and pulled down through the grain. The progress of the fumigant through the grain was traced with the thermal-conductivity (T/C) unit. In this test the fan was pulling air from only the tank being fumigated at an airflow rate of 0.046 cubic feet per minute (c.f.m.) per bushel. The fan was operated for 20 minutes. The total dosage in this test was to have been 3 pounds per 1,000 cubic feet, and the airflow was such that a complete change of air in the tank should have been accomplished in 11 minutes. However, at the end of 15 minutes, the total fumigant dosage had been applied and no appreciable amount of methyl bromide was present in the bottom of the tank. As a longer fan operation time was necessary to pull the gas to the bottom of the tank, an additional one-half pound per 1,000 cubic feet was added to the original dosage to maintain adequate concentrations in the top of the tank. Operation of the fan was continued until analysis indicated the gas had reached the 115-foot or bottom level. However, by the time the 30-minute reading was taken, no gas could be found in the bottom of the tank. A check was made with a halide leak detector around the drawoff in the basement, but no escaping gas could be detected.

The procedures for the second test were the same as those for the first, with two exceptions. In this test the rate of application was increased to 5 pounds of methyl bromide per 1,000 cubic feet and the methyl bromide was released over the time period of about 35 minutes. Concentrations of methyl bromide detected at the bottom of the tank exceeded 16 ounces per 1,000 cubic feet when the fan was stopped.

In the third test, it was thought that less channeling and better distribution of the fumi-

gant would be obtained if the airflow in the tank were reduced. This was accomplished by opening the air-duct gates to three other tanks in addition to the one being fumigated. The airflow was thus reduced to 0.0318 c.f.m. per bushel through the fumigated tank. The fan was operated for 55 minutes before the methyl bromide reached the bottom of the tank. A dosage of 4 pounds of methyl bromide per 1,000 cubic feet was used in this test.

Results

The gas distribution data and mortality of the test insects obtained in each of the three tests are presented in tables 1, 2, and 3. The adult test insects were held for 1 week after the 24-hour exposure period before mortality counts were made. Emergence counts of the immature rice weevils were made 6 weeks after their exposure to the fumigant, and mortality estimates were based upon the relative number of adult weevils emerging from treated and untreated samples.

Distribution of the methyl bromide in the first test was fairly uniform above the 65-foot level in the sorghum. Concentrations of gas below this level were too low to give good control, particularly among the immature test insects. These results indicated the need for an increase in both the dosage applied to the sorghum and the fan running time.

The distribution pattern of the fumigant in the second test indicated a marked channeling of the methyl bromide. In many of the samples taken at the center, gas concentrations were more than 100 ounces per 1,000 cubic feet, yet at no point below the 25-foot level on the north side of the tank did the gas concentration exceed 6 ounces per 1,000 cubic feet during the entire 24-hour fumigation.

TABLE 1.—*Test 1 at Placedo, Tex.: Distribution of methyl bromide after a single-pass fumigation* [1] *at a dosage of 3½ pounds per 1,000 cubic feet released into the overhead space in an elevator tank of grain sorghum, and mortality of test insects after a 24-hour exposure*

Sample number	Sampling location and depth in grain	Recovery of methyl bromide (ounces per 1,000 cubic feet) after—					Mortality of insects [2]	
		30 min.	2 hr.	4 hr.	8 hr.	24 hr.	Adult rice weevil, 1-week count	Immature rice weevil, 6-week count
							Percent	*Percent*
1	North side, 25 ft.	12	10	9	8	5	100	100
2	North side, 65 ft.	16	10	8	7	2	100	100
3	North side, 105 ft.	0	0	0	0	0	66	18
4	Center, at surface	5	5	4	3	0	100	100
5	Center, 25 ft.	8	8	8	6	2	100	100
6	Center, 45 ft.	12	10	9	8	4	100	100
7	Center, 65 ft.	11	10	7	7	3	100	54
8	Center, 85 ft.	4	4	4	4	6	97	0
9	Center, 115 ft.	0	0	0	0	3	45	0
10	South side, at surface	12	3	5	3	2	100	100
11	South side, 45 ft.	10	2	2	4	2	100	99
12	South side, 85 ft.	4	1	0	1	3	93	15
13	Overhead, at center	74	27	4	0	0	----	----

[1] Fan running time, 20 minutes; airflow, 0.046 c.f.m. per bushel.

[2] Average mortality of adult rice weevil controls, 24 percent. Average adult emergence from immature rice weevil control samples, 100 (number).

TABLE 2.—*Test 2 at Placedo, Tex.: Distribution of methyl bromide after a single-pass fumigation*[1] *at a dosage of 5 pounds per 1,000 cubic feet released in 35 minutes into the overhead space in an elevator tank of grain sorghum, and mortality of test insects after a 24-hour exposure*

Sample number	Sampling location and depth in grain	Recovery of methyl bromide (ounces per 1,000 cubic feet) after—					Mortality of insects[2]	
		30 min.	2 hr.	4 hr.	8 hr.	24 hr.	Adult rice weevil, 1-week count	Immature rice weevil, 6-week count
							Percent	*Percent*
1	North side, 25 ft.	25	13	7	8	3	100	100
2	North side, 65 ft.	4	0	0	6	3	100	98
3	North side, 105 ft.	3	0	4	2	0	100	35
4	Center, at surface	154	80	56	19	15	100	100
5	Center, 25 ft.	75	138	128	47	20	100	100
6	Center, 45 ft.	82	165	144	86	34	100	96
7	Center, 65 ft.	176	172	152	110	25	100	100
8	Center, 85 ft.	78	57	52	42	12	100	47
9	Center, 115 ft.	25	128	126	30	11	5	1
10	South side, at surface	55	75	55	11	7	100	100
11	South side, 45 ft.	26	17	16	15	5	100	100
12	South side, 85 ft.	16	10	10	11	2	100	96
13	Overhead, at center	23	16	11	4	2	100	100

[1] Fan running time, 35 minutes; airflow, 0.046 c.f.m. per bushel.

[2] Average mortality of adult rice weevil controls, 5 percent. Average adult emergence from immature rice weevil control samples, 51.5 (number).

In the third test, the reduced airflow caused by connecting the fan to three other tanks lessened the channeling effect and resulted in a more uniform distribution of the fumigant. However, the overall recovery of free interstitial gas in ounces per 1,000 cubic feet at the various levels tested was much lower in the 4 pound test than in the 5-pound test. This may have been due partly to increased sorption of the methyl bromide as a result of the slower air movement and extended fan running time.

A summary of the test insect mortality obtained in the three fumigation tests is presented in table 4. High mortality of the adult test insects was obtained in each fumigation; however, effective control of the immature rice weevils was limited to the third fumigation in which the reduced airflow was used.

A summary of the percentage of germination obtained before and after each fumigation is presented in table 5. Although the viability of the sorghum was low before fumigation, each of the methyl bromide dosages reduced the viability significantly.

Residues in samples taken before fumigation ranged from amounts less than the sensitivity level for the method of analysis—0.5 p.p.m. to as much as 50 p.p.m. Samples taken after fumigation ranged from 3 to 84 p.p.m. In 12 samples the residue increase resulting from fumigation ranged from 4 to 49 p.p.m.; in four other samples the residue increase ranged from 56 to 84 p.p.m. Considering the total residue, however, six of the samples analyzed exceeded the established tolerance of 50 p.p.m. Although bromide residue generally increased in samples taken after fumigation, no correlation was evident between the amount of methyl bromide applied and the resulting residue.

TABLE 3.—*Test 3 at Placedo, Tex.: Distribution of methyl bromide after a single-pass fumigation*[1] *at a dosage of 4 pounds per 1,000 cubic feet released into the overhead space in an elevator tank of grain sorghum, and mortaility of test insects after a 24-hour exposure*

Sample number	Sampling location and depth in grain	Recovery of methyl bromide (ounces per 1,000 cubic feet) after—					Mortality of insects[2]	
		30 min.	2 hr.	4 hr.	8 hr.	24 hr.	Adult rice weevil, 1-week count	Immature rice weevil, 6-week count
							Percent	*Percent*
1	North side, 25 ft.	20	18	10	9	7	100	100
2	North side, 65 ft.	36	26	17	15	5	100	100
3	North side, 105 ft.	3	1	1	2	0	100	96
4	Center, at surface	12	11	8	8	7	100	100
5	Center, 25 ft.	11	8	7	7	6	100	100
6	Center, 45 ft.	11	8	8	9	4	100	100
7	Center, 65 ft.	17	10	9	9	3	100	100
8	Center, 85 ft.	27	13	13	9	4	100	100
9	Center, 115 ft.	16	3	4	4	1	97	99
10	South side, at surface	18	16	13	11	5	100	100
11	South side, 45 ft.	4	6	2	9	8	100	100
12	South side, 85 ft.	4	3	6	4	2	100	100
13	Overhead, at center	12	10	10	10	3	100	100

[1] Fan running time, 55 minutes. Air-duct gates in 3 adjacent tanks left open; airflow was 0.0318 c.f.m. per bushel.

[2] Average mortality of adult rice weevil controls, 5 percent. Average adult emergence from immature rice weevil control samples, 93 (number).

TABLE 4.—*Tests 1–3 at Placedo, Tex.: Average mortality of test insects exposed for 24 hours in 3 concrete elevator tanks containing sorghum, and fumigated with methyl bromide by single-pass method*

Test[1]	Average mortality at sample point in tank					
	North side		Center		South side	
	Adult rice weevil	Immature rice weevil	Adult rice weevil	Immature rice weevil	Adult rice weevil	Immature rice weevil
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Test 1	88.7	72.7	90.3	59.0	97.7	71.3
Test 2	100	77.7	84.2	74.0	100	98.7
Test 3	100	98.7	99.5	99.8	100	100

[1] Dosages of methyl bromide used in the tests were as follows:
Test 1, 3½ pounds per 1,000 cubic feet.
Test 2, 5 pounds per 1,000 cubic feet.
Test 3, 4 pounds per 1,000 cubic feet.

TABLE 5.—*Tests 1–3 at Placedo, Tex.: Viability of sorghum grain fumigated with methyl bromide at specified dosages and 24 hour exposure*

Test [1]	Average germination	
	Before fumigation	After fumigation
	Percent	*Percent*
Test 1	51.6	31.7
Test 2	16.4	6.5
Test 3	11.8	4.3
Average, 3 tests	26.7	14.2

[1] Dosages of methyl bromide used in the tests were as follows:

Test 1, 3½ pounds per 1,000 cubic feet.

Test 2, 5 pounds per 1,000 cubic feet.

Test 3, 4 pounds per 1,000 cubic feet.

Comments

The high temperatures and high moisture content of the sorghum apparently caused considerable loss of the methyl bromide due to sorption. This loss was indicated by the pronounced difference in the fan operation time calculated to pull the methyl bromide in measurable concentrations to the bottom of the tank and the amount of time actually required to do this.

Although rapid distribution is a basic requirement in single-pass fumigations, high air velocities often cause the fumigant to follow a channel or path of least resistance as it moves down through the grain. As the total airflow is reduced, the difference between the rates of air movement in a cross-sectional area of the tank are reduced. Thus, in the third test, at a lower rate of airflow, the methyl bromide was more evenly distributed throughout the entire grain mass as it was pulled down through the tank.

TESTS AT ABILENE, KANS.

These tests consisted of the fumigation of wheat in a concrete elevator tank equipped with an experimental vertical aeration duct. The purpose of the tests was to determine the effect of the vertical aeration duct on air movement and fumigant distribution in single-pass fumigations.

Procedure

Two single-pass fumigation tests were conducted in a silo-type elevator tank. The elevator tank had a maximum grain depth of 100 feet, with an inside diameter of 20 feet. It contained about 25,000 bushels of wheat. The tank was equipped with an experimental vertical grain aeration duct, constructed of galvanized 14-gage well casing 16 inches in diameter, with perforations of the "gravel guard" type, 1/16 by 1 inch long. The duct had an overall length of 9 feet; however, only 6 feet of it was perforated. The perforated duct surface area in contact with the wheat was 25 square feet (fig. 3). A connecting pipe opening led through the hopper bottom of the tank into the central storage tunnel.

Before the tank was filled with wheat, plastic gas-sample lines were taped at 18-foot intervals to thermocouple cables that were suspended in the tank (fig. 4). One group of sample lines was located 3 feet 4 inches from the north wall of the tank, a second group was in the center of the tank, and a third group was 3 feet 4 inches from the south wall. Additional gas-sample lines were placed near the duct in the bottom of the tank and on the basement floor.

A dosage of 1.7 pounds of methyl bromide per 1,000 cubic feet, or one 50-pound cylinder per tank, was used in each fumigation.

Gas-sample readings were made with the T/C unit at 30 minutes and at 2, 4, 8, and 24 hours after application of the methyl bromide.

Static pressure readings were taken from the gas-sample lines before each fumigation to establish the operative airflow rates produced by the fan during each method of fumigation.

The fan used in these tests was a Buffalo Industrial Exhauster that had a 10-inch inlet and a 5-hp. electric motor. The fan was connected to the aeration duct with 10 feet of 12-inch-diameter flexible duct, which was attached

to the permanent connecting pipe that had been placed through the bottom of the tank during construction. Air-duct transformations had a minimum of air leaks. The flexible duct permitted exhaust airflow from the duct and the change of airflow direction for forcing the air upward through the wheat (fig. 5).

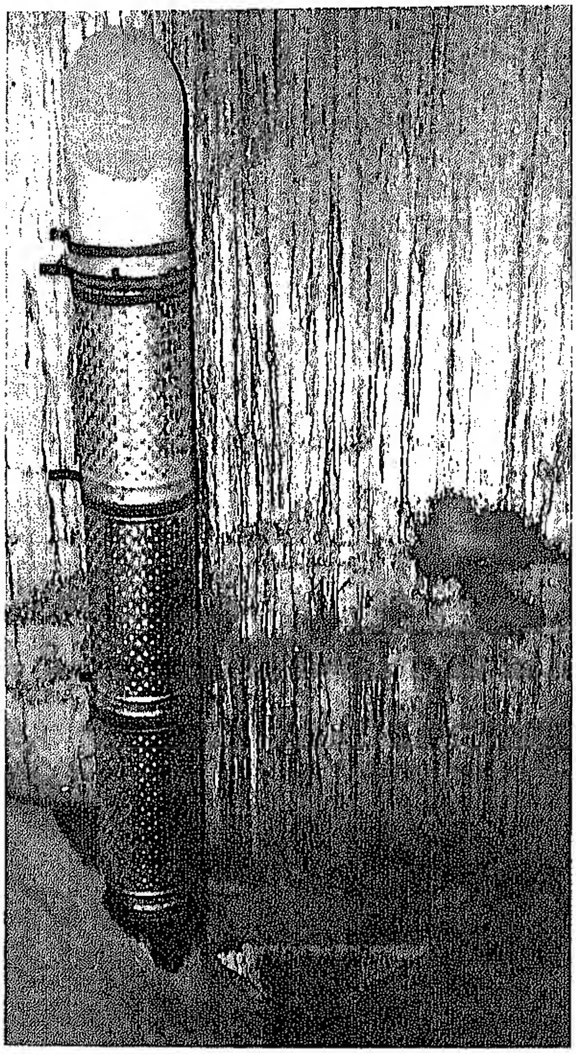

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FIGURE 3.—Vertical aeration duct.

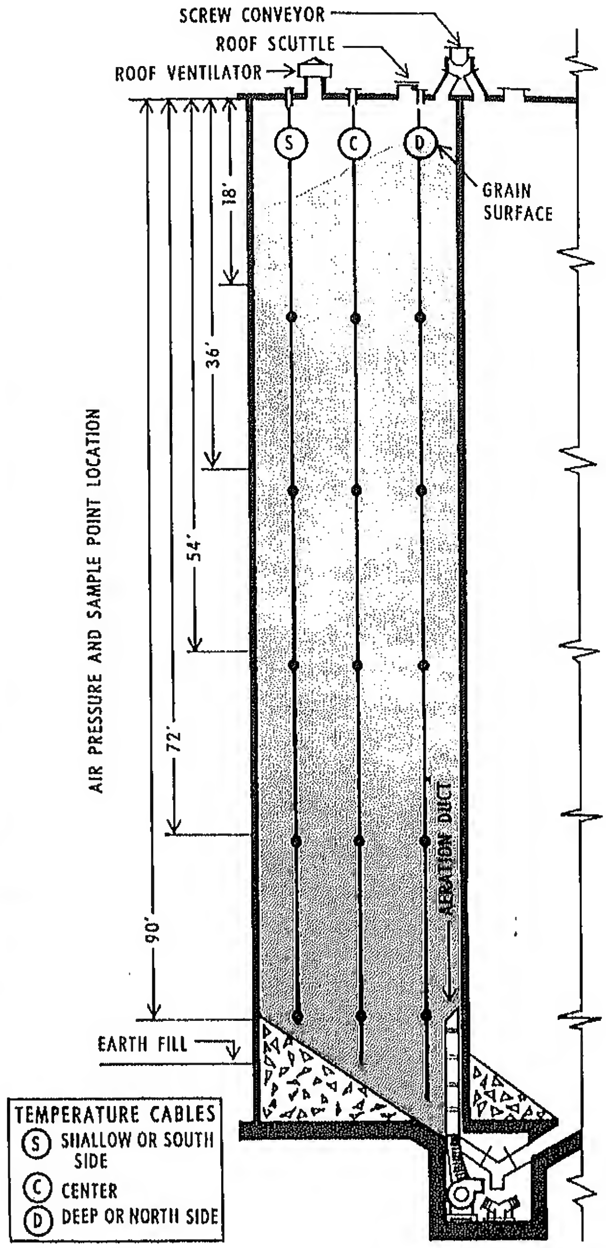

FIGURE 4.—Grain aeration system layout for test of experimental vertical aeration duct. Section of concrete storage annex with round tanks of 20-foot diameter and 100-foot maximum depth.

In the first test, the methyl bromide was released through a copper tube suspended in the overhead space, and the gas was pulled down through the wheat. In the second test, the exhaust side of the fan was connected to the aeration duct, and the methyl bromide was pushed up through the grain. The rate of gas release was checked by periodic weighing of the gas cylinder on a platform scale during application of the methyl bromide (fig. 6).

Results

Gas distribution data obtained in the fumigation tests are presented in tables 6 and 7.

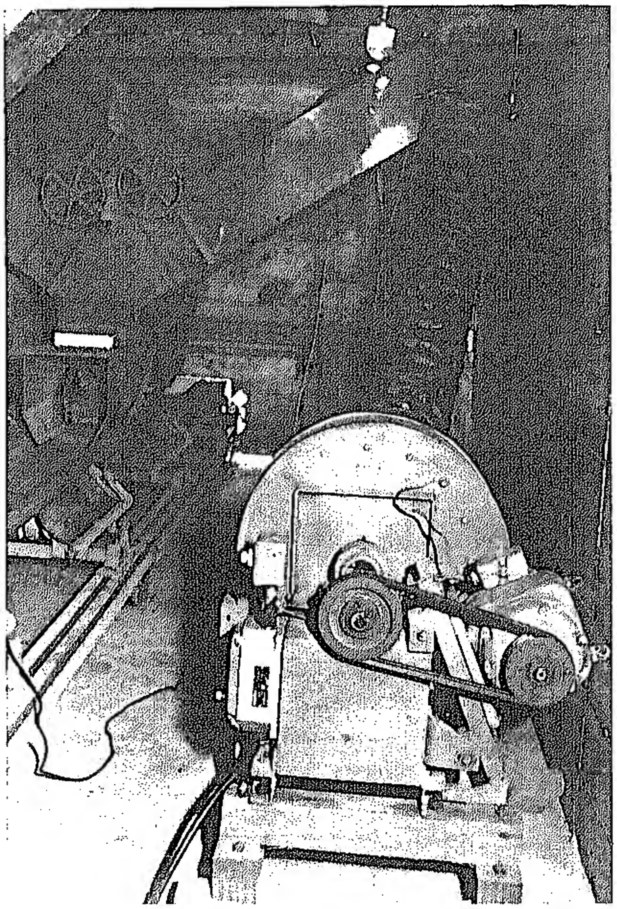

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FIGURE 5.—Closeup showing aeration fan attached to base of vertical aeration duct.

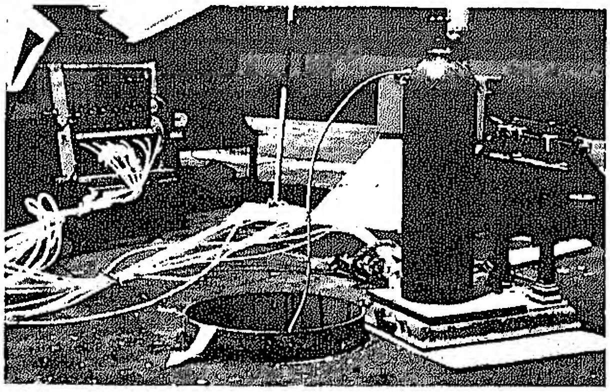

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FIGURE 6.—Gas-sample lines, methyl bromide cylinder with copper gas introduction line attached, and platform scales used to check rate of gas release.

Airflow data obtained before release of the methyl bromide in the first test indicated that about 13 minutes would be required for the fan to pull fumigant to the bottom of the tank. Starting with the initial release of methyl bromide, the rate of gas release during the 13-minute interval amounted to 15 pounds in the first 2½ minutes, 5 pounds per minute in the next 3 minutes, 4 pounds per minute in the next 4 minutes, and the remaining 4 pounds in the last 3½ minutes. The progress of the fumigant through the wheat was traced with the T/C unit. Because of the time lapse that often occurs between the time estimated to pull the fumigant through the grain and the actual distribution of gas to the bottom of a tank, the fan operation was extended until significant gas concentrations were recorded from a sample line placed near the vertical duct. The fan was operated for 5½ minutes after completion of the gas release before the methyl bromide was detected at this sample point. A later check of this sample location indicated that the gas concentrations recorded at this position could have been diluted by the intake of fresh air around the grain drawoff in the bottom of the tank. The low gas concentrations at the 18- and 36-foot levels indicate that the fan running time after completion of the gas release was longer than necessary and resulted in dilution of the gas concentrations in the top of the tank.

In the second test, the methyl bromide was released through a 7-foot ½-inch-diameter perforated pipe placed inside the verticle aeration duct. As in the first test, when the fumigant arrived at the opposite opening of the tank, the fan was stopped and the portholes were sealed. In this test the fan was operated for 15½ minutes. The rate of gas release amounted to 16 pounds in the first 3 minutes, then approximately 3 pounds per minute for 11½ minutes, so that all the gas was released in 15 minutes. Additional air was blown into the tank for less than 1 minute after completion of the gas release.

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TABLE 6.—*Test 1 at Abilene, Kans.: Distribution of methyl bromide resulting from a single-pass fumigation at a dosage of 1.7 pounds per 1,000 cubic feet, in which the gas was pulled down through a wheat-filled elevator tank*[1]

Sample number	Sampling location and distance from roof	Recovery of methyl bromide (ounces per 1,000 cubic feet)				
		30 min.	2 hr.	4 hr.	8 hr.	24 hr.
1	Center, in overhead space	5	4	4	2	0
2	North side, 18 feet	5	6	4	3	2
3	North side, 36 feet	10	10	10	7	6
4	North side, 54 feet	17	15	15	9	9
5	North side, 72 feet	24	23	22	16	13
6	North side, 90 feet	21	22	22	17	14
7	Center, 18 feet	10	12	13	8	9
8	Center, 36 feet	15	15	15	8	9
9	Center, 54 feet	21	20	18	12	8
10	Center, 72 feet	34	30	27	17	12
11	Center, 90 feet	30	25	23	16	13
12	South side, 18 feet	7	10	11	6	5
13	South side, 36 feet	13	13	15	9	7
14	South side, 54 feet	22	20	20	13	10
15	South side, 72 feet	31	25	24	16	11
16	South side, 90 feet	20	20	20	15	12

[1] Fan-operating time, 18½ minutes; airflow, 0.045 c.f.m. per bushel; exposure, 24 hours.

TABLE 7.—*Test 2 at Abilene, Kans.: Distribution of methyl bromide resulting from a single-pass fumigation at a dosage of 1.7 pounds per 1,000 cubic feet, in which the gas was pushed up through a wheat-filled elevator tank*[1]

Sample number	Sampling location and distance from roof	Recovery of methyl bromide (ounces per 1,000 cubic feet)				
		30 min.	2 hr.	4 hr.	8 hr.	24 hr.
1	North side, in overhead space	12	4	4	0	0
2	North side, 18 feet	16	10	8	5	2
3	North side, 36 feet	19	10	9	6	5
4	North side, 54 feet	16	8	8	4	4
5	North side, 72 feet	24	16	15	9	7
6	North side, 90 feet	27	16	15	9	8
7	Center, 18 feet	24	15	14	7	3
8	Center, 36 feet	22	12	10	9	5
9	Center, 54 feet	23	13	11	10	6
10	Center, 72 feet	29	17	15	12	8
11	Center, 90 feet	19	13	12	10	7
12	South side, 18 feet	33	18	14	13	5
13	South side, 36 feet	40	22	18	16	10
14	South side, 54 feet	40	26	22	19	12
15	South side, 72 feet	34	24	22	20	14
16	South side, 90 feet	40	25	22	20	13

[1] Fan-operating time, 15½ minutes; airflow, 0.0457 c.f.m. per bushel; exposure, 24 hours.

sure operation produced an airflow of about 0.046 c.f.m. per bushel.

In evaluating the distribution patterns produced by the two single-pass methods of fumigation, particular emphasis was placed on the differences in gas concentrations of the south, center, and north sample points at each level. On this basis of comparison, the first test—fan exhausting—produced a more uniform distribution of the fumigant than was obtained in the second test—pushing air upward through the grain. In addition, the initial gas concentrations recorded in the second test indicate a slight channeling of the fumigant up the south side of the tank. The lowest overall gas concentrations recorded in the wheat mass in both fumigation tests were found at the 18-foot level on the north tier of sample lines, directly below the peak where the wheat was piled most deeply. Channeling of the fumigant around the wheat peak was particularly evident in the second fumigation, in which gas concentrations ranged from 16 ounces per 1,000 cubic feet at the 18-foot level beneath the wheat peak to 33 ounces per 1,000 cubic feet at the same level on the south or shallow side of the tank.

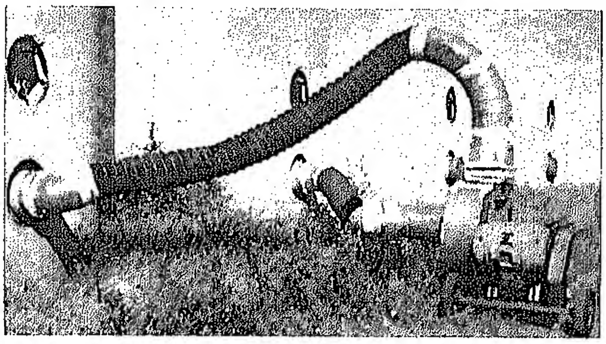
TEST AT TOPEKA, KANS.

A fumigation test was conducted on wheat stored in two adjacent elevator tanks at the Topeka Mill and Elevator Company, Topeka, Kans. The purpose of this test was to secure data on gas distribution during simultaneous recirculation of a liquid fumigant in two adjacent silo-type elevator tanks.

Procedure

Two silo-type elevator tanks were fumigated simultaneously with a liquid fumigant composed of carbon tetrachloride, 82.5 percent by weight; carbon disulfide, 16.5 percent by weight; and inert ingredients, 1 percent by weight. According to the manufacturer, the inert ingredients, while acting as a fire inhibitor, may impart an insignificant bromide residue to the grain. The fumigant was applied at the rate of 1.6 gallons per 1,000 bushels of wheat.

The two tanks were adjacent to each other. One was designated as tank 45 and the other tank 46. Each tank was 142 feet high and contained approximately 31,000 bushels of wheat. The moisture content of the wheat averaged 11.6 percent in tank 45 and 11.7 percent in tank 46. The average grain temperature in tank 45 was 71.8° F. and 69° in tank 46. The tanks were connected at the top and bottom by sections of 10-inch flexible hose (figs. 7 and 8). A fan unit, powered by a 15-hp. motor, was placed between the bottom connections of the two tanks, and distributed the fumigant by recirculation. The intake of the fan was connected to the aeration duct in tank 46, and the exhaust of the fan was connected to the aeration duct in tank 45, thus completing the circulation system in both tanks. The fan was operated for 2 hours and 20 minutes to distribute the fumigant.



BN-15806

FIGURE 7.—Fan unit and external connections between the aeration ducts at the base of the tanks.

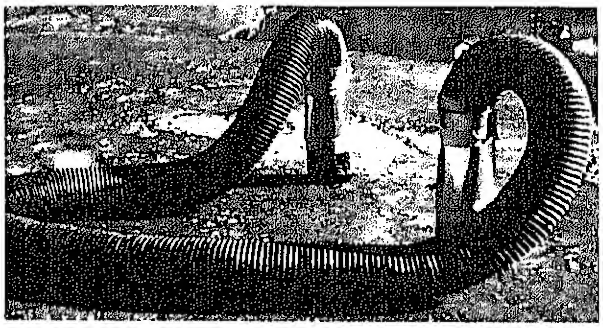


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FIGURE 8.—Flexible hose connections at the top of the tank.

Before the tanks were filled with grain, two groups of plastic gas sampling lines with

sampling points spaced 20 feet apart were suspended in each tank. Two small cloth bags were taped to the lines at each sampling point. One bag contained a sample of grain to be used for fumigant residue analyses, and the other contained test insects (fig. 9). Adult confused flour beetles and a sample of grain containing immature rice weevils were enclosed in small screen cages and placed in cloth bags labeled as to the position they would occupy in the grain. The control insects were subjected to similar moisture and temperature conditions and were placed in a separate tank not under fumigation.

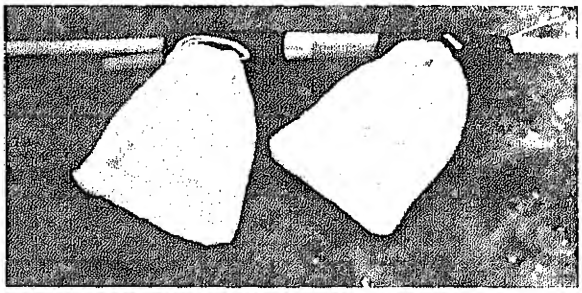

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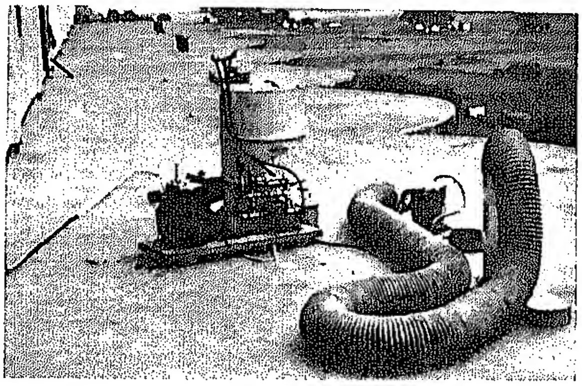
FIGURE 9.—Closeup of the grain and insect bags taped to the plastic gas sample lines.

The fumigant was introduced into the overhead space through two fog nozzles suspended above the grain surface. Fifty gallons of fumigant were pumped into the top of each tank by a small, gasoline-powered centrifugal pump (fig. 10).



BN-16895

FIGURE 10.—Pump used to apply the liquid fumigant.

Gas samples were taken with the T/C unit at 30 sample locations at intervals of 4, 8, 24, and 48 hours after the fumigant was applied. As the concentrations of the individual components of the fumigant cannot be determined by the T/C instrument, the readings were expressed as units of the galvanometer scale. Additional gas samples for mass spectrometry analyses of each component were taken in metal tubes with stopcocks at each end. The metal tubes were placed ahead of the T/C unit on the sample lines, and the T/C readings were made at the same time that the gas samples were taken.

The aeration systems in the two tanks included the same type and size of tight-walled connecting pipes 14½ inches in diameter. The connecting pipes extended from the outside or exit opening of the perforated aeration duct on the tank floor. The aeration ducts were in the same relative position on the tank floor, starting at the outside wall and extending toward the grain drawoff opening. The cross section of the duct was semicircular in tank 46 and round in tank 45. The round duct was longer and had a smaller cross section than the semicircular duct.

Static pressure readings were made after the fan had operated 20 minutes and 1½ hours. Additional readings were taken during the evacuation of the fumigant from the tanks. Both tanks were evacuated simultaneously by the use of a Y-adapter connecting the duct in each tank to the intake of the fan (fig. 11).

A special screen, constructed from metal grills, was placed in the elevator boot of each tank to trap the test insect and grain bags as the tanks were emptied.

Results

The gas distribution data determined by the T/C unit and the test insect mortality counts are presented in table 8. Mortality counts of the adult insects were made after completion of the 48-hour exposure period. Emergence counts of the immature rice weevils were made 6 weeks after their exposure to the fumigant, and mortality estimates were based upon the relative number of adult weevils emerging from treated and untreated samples. Gas concentrations determined by mass spectrometry analyses are shown in table 9. Results of the

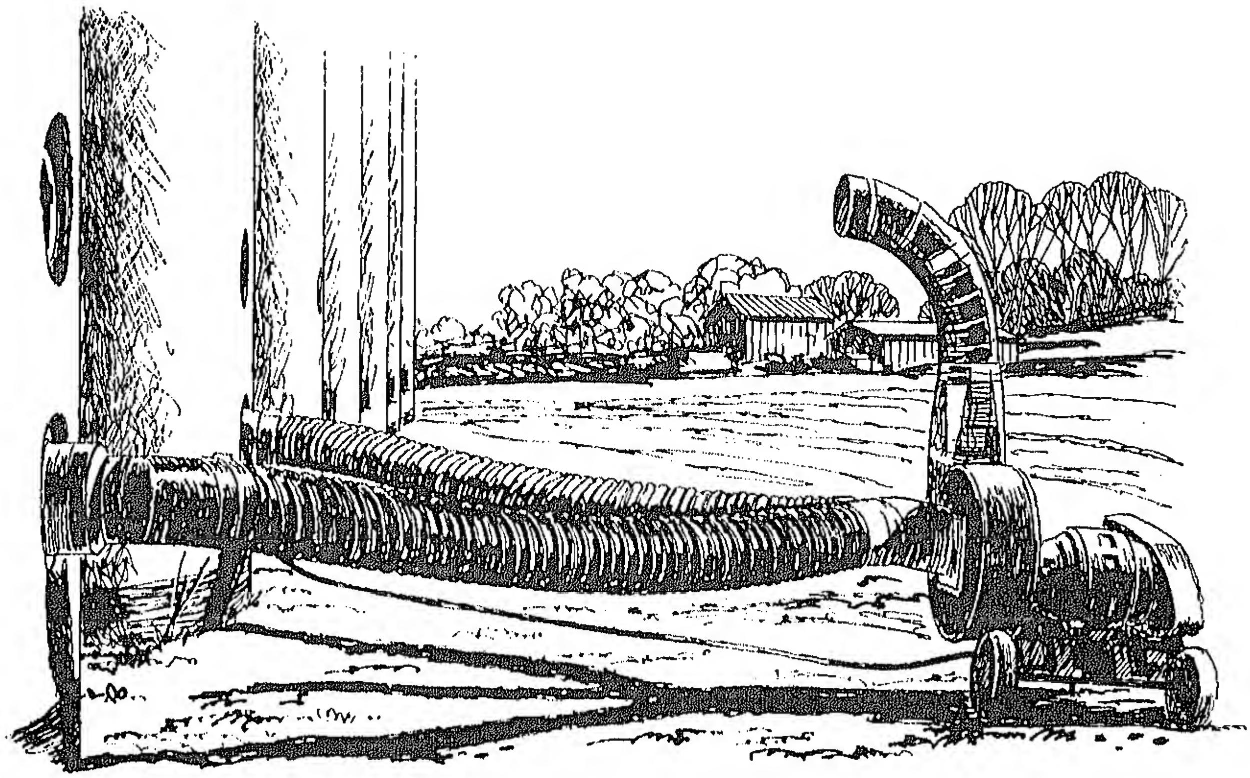


FIGURE 11.—Connections made to evacuate the fumigant simultaneously from both tanks.

mass spectrometry analyses did not indicate that a significant separation of the fumigant components resulted from the movement of the fumigant through nearly 280 feet of wheat.

Both methods of analyses indicated that the initial distribution of the fumigant was very uniform in tank 45, but not in tank 46. Concentrations were slightly higher than average in the top of tank 46 and below average at the 80- and 140-foot levels.

No apparent lateral movement of the fumigant occurred after the fan was stopped; however, there was some settling of the fumigant, particularly in the CCl_4 concentrations, to the bottom in tank 46 during the 48-hour exposure period.

High mortality of the test insects was obtained in both tanks, except at the center 80-, 100-, and 120-foot levels in tank 46. Low concentrations of both CS_2 and CCl_4 were recorded at these locations. No explanation is evident for the low gas concentrations. Although airflow data indicated an adequate air movement through this part of the grain mass, sample readings taken during the operation of the fan showed a marked decrease in initial gas concentration at all points between the 80- and 120-foot levels.

Airflow estimates based on static pressure measurements made in each tank are listed in table 10.

There was no increase of bromide residue in the wheat samples taken after fumigation of the two elevator tanks.

Comments

The fumigation test at Topeka demonstrated the feasibility of using a second tank as a return duct, thus permitting recirculation of grain fumigants without the addition of a separate return duct.

In fumigations of this type, the location of the fan is of prime importance. When the fan was inserted between the ducts at the bottom of the tanks, the positive pressures produced on the exhaust side of the fan were contained within the grain mass in tank 45. Somewhere between the 20-foot level and the overhead

space in tank 45, the air movement came under the influence of the intake of the fan. Thus, the pressure reading in the overhead space of each tanks was negative. Had the fan been located between the connections at the top of the tank, the positive pressure produced on the exhaust side of the fan would have caused excessive leakage of the fumigant around the manhole seals in the tops of the tanks.

Another leakage problem frequently encountered in recirculating fumigants with existing aeration fans is caused by the lack of gastight construction in the fan housing. In the test, a considerable amount of fumigant escaped around the housing joints on the exhaust side of the fan during the 2⅓ hours' recirculation of the fumigant.

TABLE 8.—*Test at Topeka, Kans.: Distribution of gas and percent mortality of adult confused flour beetles and immature rice weevils resulting from recirculation of a liquid fumigant in 2 coupled elevator tanks filled with wheat* [1]

Tank and sample number	Sampling location and distance from roof	Gas recovery (unit deflections on the galvanometer scale)				Mortality of insects [2]	
		4 hr.	8 hr.	24 hr.	48 hr.	Adult confused flour beetles, 48-hr. count	Immature rice weevils, 6-week count
		Units	*Units*	*Units*	*Units*	*Percent*	*Percent*
Tank 45							
1	Center, in overhead space	100	30	5	3	100	100
2	Center, 20 feet	76	48	25	18	100	95
3	Center, 40 feet	84	54	33	25	100	100
4	Center, 60 feet	86	57	35	28	100	95
5	Center, 80 feet	90	61	40	33	100	100
6	Center, 100 feet	91	64	42	35	100	100
7	Center, 120 feet	90	66	42	38	100	100
8	Center, 140 feet	94	70	46	55	100	95
9	East, 20 feet	84	240	102	51	100	100
10	East, 40 feet	84	73	91	62	100	91
11	East, 60 feet	85	62	59	43	100	100
12	East, 80 feet	89	63	48	48	100	91
13	East, 100 feet	92	67	50	41	([3])	100
14	East, 120 feet	91	68	49	42	100	100
15	East, 140 feet	98	69	84	77	100	100
Tank 46							
16	Center, in overhead space	105	35	7	3	100	100
17	Center, 20 feet	104	74	40	21	100	100
18	Center, 40 feet	104	67	35	27	100	100
19	Center, 60 feet	94	60	34	28	100	91
20	Center, 80 feet	66	46	29	25	70	76
21	Center, 100 feet	42	37	22	26	10	48
22	Center, 120 feet	23	29	26	45	20	100
23	Center, 140 feet	27	150	152	146	100	100

See footnotes at end of table.

TABLE 8.—*Test at Topeka, Kans.: Distribution of gas and percent mortality of adult confused flour beetles and immature rice weevils resulting from recirculation of a liquid fumigant in 2 coupled elevator tanks filled with wheat* [1]—Continued

Tank and sample number	Sampling location and distance from roof	Gas recovery (unit deflections on the galvanometer scale)				Mortality of insects [2]	
		4 hr.	8 hr.	24 hr.	48 hr.	Adult confused flour beetles, 48-hr. count	Immature rice weevils, 6-week count
		Units	*Units*	*Units*	*Units*	*Percent*	*Percent*
Tank 46—Con.							
24	West, 20 feet	112	240	92	60	100	100
25	West, 40 feet	92	130	85	59	100	100
26	West, 60 feet	58	80	67	48	100	100
27	West, 80 feet	58	57	59	55	100	100
28	West, 100 feet	52	57	68	71	100	91
29	West, 120 feet	67	84	93	102	100	100
30	West, 140 feet	74	95	110	126	100	100

[1] Fumigant consists of carbon tetrachloride, 82.5 percent by weight; carbon disulfide, 16.5 percent by weight; and inert ingredients acting as a fire suppressant, 1 percent by weight. Dosage, 1.6 gallons of fumigant to 1,000 bushels of wheat. Fan operating time, 2 hours and 20 minutes. Airflow upward in tank 45, 0.0155 c.f.m. per bushel; airflow downward in tank 46, 0.0165 c.f.m. per bushel.

[2] Average mortality of adult confused flour beetle controls, 4.3 percent; average adult emergence from immature rice weevil controls, 21 (number).

[3] Samples were lost.

TABLE 9.—*Test at Topeka, Kans.: Gas concentrations determined by mass spectrometry analyses in elevator tanks containing wheat and fumigated with a liquid fumigant at the rate of 1.6 gallons per 1,000 bushels* [1]

Tank, sampling location, and distance from roof	Time after application	Concentrations per 1,000 cubic feet		
		Carbon disulfide (CS_2)	Carbon tetrachloride (CCl_4)	Fire suppressant
Tank 45	*Hours*	*Ounces*	*Ounces*	*Ounces*
Center, in overhead space	4	4.3	36.3	----
Center, in overhead space	24	.16	14.7	----
Center, in overhead space	48	.64	8.3	----
Center, 20 feet	4	61.5	114.6	1.6
Center, 20 feet	8	9.8	67.2	.8
East side, 20 feet	8	10.4	79.4	.32
Center, 20 feet	48	6.4	41.3	----
East side, 20 feet	48	10.7	84.3	----
Center, 40 feet	4	13.9	104.2	1.9
Center, 40 feet	24	7.0	49.9	----
Center, 40 feet	48	6.7	51.2	----
East side, 40 feet	48	5.4	53.6	----

See footnote at end of table.

TABLE 9.—*Test at Topeka, Kans.: Gas concentrations determined by mass spectrometry analyses in elevator tanks containing wheat and fumigated with a liquid fumigant at the rate of 1.6 gallons per 1,000 bushels* [1]—Continued

Tank, sampling location, and distance from roof	Time after application	Concentrations per 1,000 cubic feet		
		Carbon disulfide (CS_2)	Carbon tetrachloride (CCl_4)	Fire suppressant
Tank 45—Con.	*Hours*	*Ounces*	*Ounces*	*Ounces*
Center, 60 feet	4	16.8	100.5	1.2
Center, 60 feet	8	.16	1.3	----
Center, 60 feet	24	.32	1.3	----
Center, 60 feet	48	5.8	54.9	----
East side, 60 feet	48	5.4	64.6	----
Center, 80 feet	4	11.2	108.5	2.2
Center, 80 feet	8	.96	8.6	----
Center, 80 feet	24	6.1	39.4	----
Center, 80 feet	48	6.7	57.9	----
Center, 100 feet	4	24.3	125.6	1.9
Center, 100 feet	8	2.4	17.3	----
Center, 100 feet	24	7.0	55.5	----
Center, 100 feet	48	5.8	54.9	----
Center, 120 feet	4	17.0	105.3	2.2
Center, 120 feet	24	7.4	40.0	----
Center, 120 feet	48	7.0	55.5	----
Center, 140 feet	4	17.3	112.5	1.9
Center, 140 feet	8	11.5	78.9	1.2
Center, 140 feet	24	.32	1.9	----
Center, 140 feet	48	15.2	55.5	----
East side, 140 feet	48	7.8	93.0	----
Tank 46				
Center, in overhead space	48	0.32	19.0	0.32
Center, 20 feet	4	17.8	134.2	2.1
Center, 20 feet	8	14.1	101.6	1.2
Center, 20 feet	48	6.9	67.2	----
Center, 40 feet	4	15.8	114.6	2.2
Center, 40 feet	24	7.4	62.2	----
Center, 40 feet	48	4.0	30.9	----
Center, 60 feet	4	14.1	91.8	1.9
Center, 60 feet	8	8.8	73.3	.32
Center, 60 feet	24	5.8	42.7	----
Center, 60 feet	48	7.0	33.3	----
Center, 80 feet	4	9.8	65.3	----
Center, 80 feet	8	5.4	39.4	.8
Center, 80 feet	24	.64	8.2	----
Center, 80 feet	48	3.7	29.6	----

See footnote at end of table.

TABLE 9.—*Test at Topeka, Kans.: Gas concentrations determined by mass spectrometry analyses in elevator tanks containing wheat and fumigated with a liquid fumigant at the rate of 1.6 gallons per 1,000 bushels* [1]—Continued

Tank, sampling location, and distance from roof	Time after application	Concentrations per 1,000 cubic feet		
		Carbon disulfide (CS_2)	Carbon tetrachloride (CCl_4)	Fire suppressant
Tank 46—Con.	*Hours*	*Ounces*	*Ounces*	*Ounces*
Center, 100 feet	4	5.0	33.9	----
Center, 100 feet	8	.64	.38	----
Center, 100 feet	24	3.7	37.0	----
Center, 100 feet	48	3.4	29.6	----
Center, 120 feet	8	3.0	26.6	----
Center, 120 feet	24	3.4	32.6	----
Center, 120 feet	48	2.4	9.8	----
West side, 120 feet	48	3.0	39.5	----
Center, 140 feet	4	.64	8.0	----
Center, 140 feet	8	37.0	338.9	1.9
Center, 140 feet	24	14.1	142.2	----
Center, 140 feet	48	23.5	328.3	----
West side, 140 feet	48	17.0	207.5	----

[1] Airflow upward in tank 45; downward in tank 46.

TABLE 10.—*Test at Topeka, Kans.: Airflow estimates based on measured static pressure drop in wheat*

Item	Tank 45, forcing (up)	Tank 46, suction (down)
Volume of tank ---- cubic feet	35,600	35,
Approximate volume of grain ---- do	34,850	34
Empty space above grain ---- do	750	
Void space in grain [1] ---- do	13,940	
Total air in tank ---- do	14,690	
Time for change of air in tank ---- minutes	530.1	
Average static pressure drop per foot of grain [2] (water) ---- inches	.0441	
Static pressure drop per foot of grain (using 1.15 pack factor) (water) ---- do	.0383	
Airflow per square foot of tank area ---- cubic feet per minute	1.95	
Total airflow through tank ---- do	488	
Rate of airflow per bushel ---- do	.0155 or 1/64	

[1] Based on 40 percent of total. No correction made for grain pack factor.
[2] Measured at vertical intervals of 20 feet in wheat.

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